







Patients Behaviour Monitoring Inside a Hospital Garden: Comparison Between RADAR and GPS Solutions

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Abstract. Monitoring the behaviors of inpatients with reduced cognitive abilities within an area of a hospital can provide important information on how patients live in that space and which part is of most interest. In this paper two different techniques are applied to perform this monitoring in an outdoor space; the former is based on the GPS positioning and timing, and the subjects must wear a suitable device, while the latter is based on a non-contact radar technology. Radar sensors are in fact nowadays very powerful even for medical applications and can be used to monitor patients within environments. In this work, the behaviors monitoring of the people inside the garden of a retirement house is considered. The two different techniques are used for tracking the subjects and the results are compared.

Keywords: GPS · AAL · Tracking · Radar · Smartwatch

1 Introduction

The availability of automotive radars, introduced to improve vehicle safety, has made it possible to have very reliable radar systems at a relatively low cost. As required by the standard they transmit with a carrier frequency of around 80 GHz, and to provide high performances the transmission bandwidth is very large [11, 17]. These systems are powerful not only in the automotive field but can be also applied for improving the safety of the living environment, where the detection of people and the prediction of any dangerous situations represents another classical problem that can be solved with radars [1, 13]. Thanks to the performance of the modern mmWave automotive radars, it is possible to track a person inside an ambient with a very good resolution [8]. Another key point on the usage of these systems for Ambient Assisted Living (AAL) is the capability offered by the Multiple In Multiple Out (MIMO) technology. With MIMO radars non only the distance can be detected, but also the angular position of a target, through the evaluation in a very fast way of the Angle of Arrival (AoA) without moving the sensor [12]. Modern four-dimensional MIMO automotive radar

provides a very high angular resolution, as in the automotive field AoA information is crucial for autonomous driving. The performance of typical automotive radars makes them interesting in the AAL context to track people within the living environment and obtain information on their behavior through suitable processing of the radar signal.

Monitoring the activity of a person can be done also with other radio technology, for example in [16, 18] an approach based on Long Range (LoRa) communication is proposed. In these cases, a specific device must be suited by the patient, and also the area of usage must be covered by the LoRa access points. Another approach to solving the problem of tracking people is to use a smartwatch equipped with GPS. The usage of a smartwatch for healthcare applications is very common as the device integrates many sensors that can be used for monitoring the conditions of a patient. In [14], a smartwatch is used to monitor a patient affected by dementia, and in [3] the GPS is used to collect information about Schizophrenic Patients. With this device the tracking of a person inside an area is simple to implement but, since the smartwatch needs to receive the GPS satellite signal to obtain its position, its operation is precluded indoor, or where the signals of satellites cannot be received. On the other hand, smartwatches equipped with GPS receivers are very popular and relatively low cost and allow a relatively accurate definition of the position.

In this work, the two different approaches are applied to study the movements of people within an outdoor environment, the garden of a retirement home. In this garden, areas of sensory stimulation have been created, through flowerbeds with colored flowers, aromatic plants, and the diffusion of music. This work aims to propose a technological tool that can objectively define which of these areas attract the attention of patients with reduced cognitive abilities, and how long patients stay within these areas. The paper describes the technologies used, and the results obtained are shown and compared, highlighting the strengths and weaknesses of the two proposed technologies.

2 The Considered Technologies

2.1 Radar Systems

The radars used in this work are two 4D imaging radars, that are designed for Advanced Driver-Assistance Systems (ADAS) applications. They implement the Frequency Modulated Continuous Wave (FMCW) scheme and the MIMO technology. The transmitted signal ranges from 77 GHz to a maximum of 81 GHz and the bandwidth may reach the value of 4 GHz. Each radar board is composed of four single-chip radar, each of one is characterized by four receivers and three transmitters antennas. The position of all the antennas provides a very high resolution along the azimuth plane, but it is also possible to detect the elevation of the targets [6]. These devices are the new frontier in ADAS as their capabilities to track and classify the target type are very promising [9, 15]. In this work, only the position along the azimuth plane is of interest, and the data collected by the elevation elements of the antenna array are neglected.

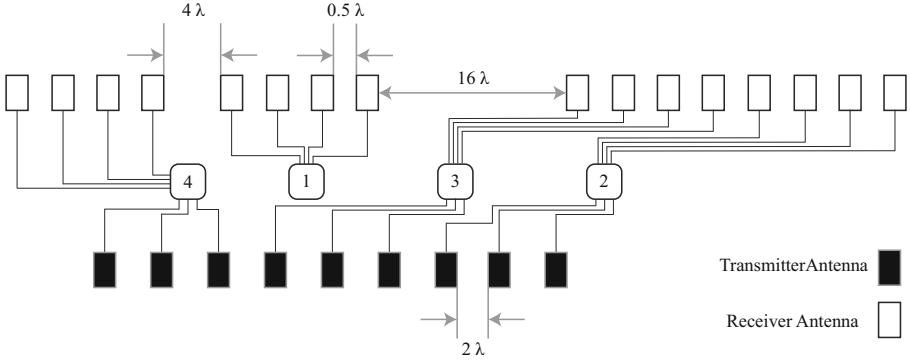


Fig. 1. MIMO antennas layout for improving AoA resolution along the azimuth plane.

A description of the transmitter and receiver antennas is shown in Fig. 1, where the horizontal distance between the antennas connected to the same chip and between the antennas connected to the four chips are highlighted. In Fig. 1, λ is the wavelength of the transmitted signal. The positions of the antennas are fundamental to realizing the virtual array used in this work and this is obtained by performing a spatial convolution between the transmitter and the receivers antennas. Considering only the transmitters indicated in Fig. 1, the result is a planar array of 86 elements along the azimuth plane. To avoid the overlapping of the signals transmitted, different channel access schemes can be assigned to the two radar boards, the Time Division Multiplexing and the Binary Phase Modulation [10]. For simplicity and to avoid any phase imperfection the first one is chosen, so each transmitted chirp is sent by following the order configured inside the device. The transmitted chirps are grouped inside a frame and at least one chirp for each transmitter must be sent. In the FMCW scheme, at the receiver side, the transmitted and the received signals are mixed and the result is another signal called beat signal, which is sampled by an analog to digital converter. The higher the frequency of the beat signal, the greater the distance to the target that reflected the radar signal. The maximum detectable range R_{max} is related to the maximum beat frequency according to the equation:

$$R_{max} = \frac{c \cdot f_b}{2 \cdot S} \tag{1}$$

where c is the speed of light, f_b the beat frequency and S the chirp ramp slope [7]. Since the maximum detectable beat rate is related to the sample rate, increasing it allows a higher range to be detected. All the collected data are stored inside a Solid State Drive (SSD) that is directly connected to the radar board. For each device, the collected samples of the beat signals are stored inside a raw file that contains the complex values of each sample.

2.2 Smartwatch with GPS

Most of the modern smartwatches are equipped with GPS and these devices are the simplest way to detect their position. In this work two models of smartwatches are considered:

- Garmin Fenix 6
- Garmin VivoActive 4

Both the models are designed to support the user during a training session, and can provide information from different on board sensors about: user location, altitude, speed, and GPS accuracy; or about user activity such as heart rate or acceleration.

The devices can record all the sensors' data by using an appropriate application called "RawLogger" and a custom Python script was developed to save them on a computer. The data are not directly exported in a human-readable format, so the script can extract the data and store them inside a Comma Separated Value (CSV) file. For each row, the file contains a sample of each sensor and the samples are marked with a progressive time-stamp. In this case, only the GPS data are considered as only the position of the user is of interest for this work.

GPS data can be processed not only with the custom developed software but also through the cloud platform provided by GARMIN, the vendor of the devices. In Fig. 2 the results of the two processing methods are compared. Data are acquired by Fenix 6, and the blue and red line represent the results of custom and cloud methods respectively. From the figure it is possible to see how both methods provide very similar results, the curves being almost perfectly overlapping. On the contrary in Fig. 3 a comparison between the accuracy of two smartwatches worn by the same person can be found. In the figure, red line shows the result obtained with Fenix 6, while blue line the one obtained with VivoActive 4.

The different paths represented in the figure are the result of the different hardware inside the smartwatches, which are characterized by a different precision. It is also necessary to take into account the different number of satellites that each smartwatch can receive, since this leads to a different precision.

3 Measurement Setup and Radar Signal Processing

3.1 Measurement Area and Systems Configuration

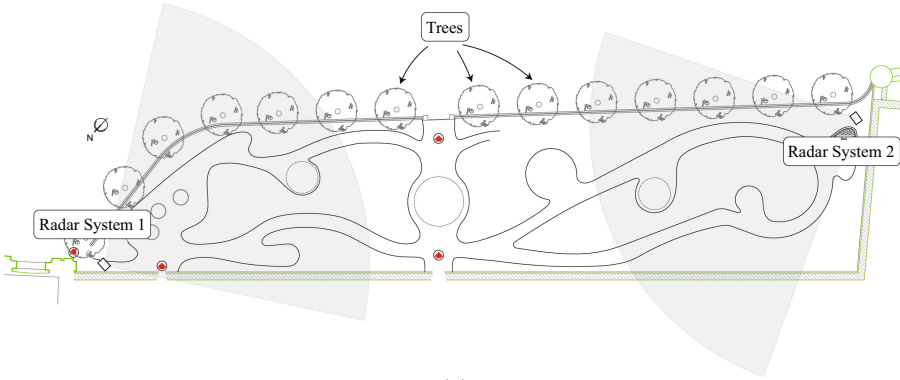
The measurement area is a garden of a retirement home whose plan can be found in Fig. 4a. Inside the garden are present trees, metal chairs and other stuff such as a gazebo and a small pool. The green lines in the figure represent walls and the grey line near the perimeter trees is a metal fence. From Fig. 4b the presence of the trees and walls is highlighted. As the purpose of this work is to identify and track the position of the people inside the garden all these objects contribute, through the global clutter produced by the environment on the radar signal, to a decrease in the accuracy of the position.



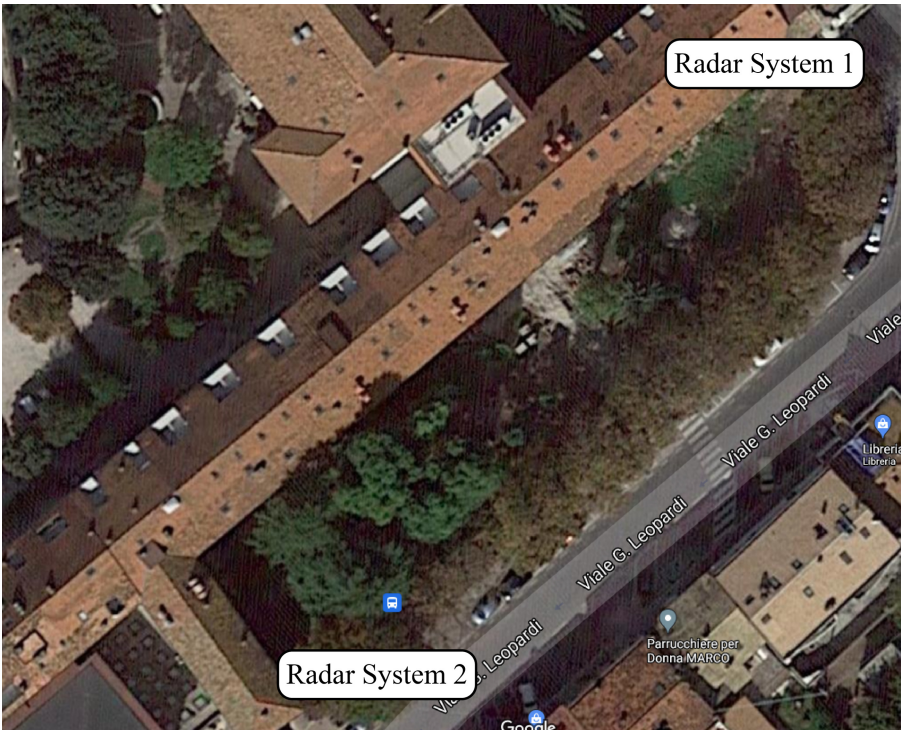
Fig. 2. Comparison between the custom processing and the cloud processing (Color figure online)



Fig. 3. GPS positioning detection comparison with the two different smartwatches. (Color figure online)



(a)



(b)

Fig. 4. Measurement setup area: a) plan of the garden and position of the two radar systems; b) picture from the satellite of the same area. (Color figure online)

The longest sides of the garden are about equal to 90 m and the shortest 25 m. The two radar systems, whose positions are shown in the figure, are configured

with the same parameters so to avoid mutual interference. The configuration parameters can be found in Table 1.

Table 1. Radar configuration parameters.

| Parameter | Value |
|-----------------------------|-------|
| Start frequency [GHz] | 77 |
| Chirp slope [MHz/ μ s] | 49.97 |
| Idle time [μ s] | 5 |
| ADC start time [μ s] | 6 |
| Ramp end time [μ s] | 80 |
| ADC sampling rate [MHz] | 10 |
| Number of samples per chirp | 512 |
| Chirps per frame | 12 |
| Inter-frame interval [ms] | 1000 |

The description of the parameters follows:

- Start Frequency: carrier start frequency, with this system the carrier goes from 77 to a maximum of 81 GHz;
- Chirp Slope: Slope of the chirp frequency, a high slope can produce a chirp with a bigger bandwidth in less time;
- Idle time: idle time between two chirps, this time is used to restore the ramp generator inside the device;
- Ramp end Time: time length of the transmitted chirp;
- ADC Sampling Rate: sampling rate of the beat signal at each receiver;
- ADC start time: the chirp frequency is controlled by a ramp generator, in the first part the ramp is not linear so this time is used to neglect this samples;
- Number of samples per chirp: the number of samples used in each chirp;
- Chirps per frame: as described before the transmitted chirps are grouped in frames;
- Inter-frame Interval: each frame has a certain duration, this time is always less than Ramp end Time \times Chirps per frame.

With the configuration of Table 1, the maximum detectable range is around 30 m so the two radar systems can detect less than half of the garden area. The choice of this configuration is related to the aperture of the antenna system and the reduction of the range capability can decrease the amount of undesired clutter. The Inter-Frame Interval is chosen equal to one second, in order to limit the total amount of data produced by the system. As the observed targets are moving slowly inside the area, the beat signal, and then the spatial data, can be sampled at a slow rate.

To perform the measurements with the GPS each person wears the Fenix 6 on the left arm and the VivoActive 4 on the right arm. The GPS data are collected by the two devices and processed in both the ways, cloud and custom.

3.2 Radar Signal Processing

The samples of each beat signal are taken from each data file and reorganized in a five-dimensional data-cube, are then stored following this method:

- The samples of each chirp are the fast-time samples and these samples are stored along with the rows of a matrix, each column of this matrix contains the samples of each transmitted chirp and are called slow-time;
- For each transmitted chirp, the reflected signal is received by all the elements of the virtual array so along two other dimensions the samples related to the azimuth and the elevation plane are stored;
- As this four-dimensional hyper-cube is generated for each frame the fifth dimension is the time evolution of the acquisition.

Once the five-dimensional data-cube was built the range-azimuth maps are evaluated, since the main purpose of the radar system is to track the position of the people inside the area. The maps are obtained by performing a bi-dimensional Fast Fourier Transform on the plane fast-time - azimuth. The result is a cube where each “slice” is a range-azimuth map. In each range-azimuth map, a two-dimensional Constant False Alarm Rate (CFAR) [8] detector is applied, in order to reduce most of noise and clutter. The environment where the measurements are performed is very dense and trees, lightning lights, and big flowerpots are present; the 2D-CFAR provides a more clear view of the maps obtained from the radar. An example of the obtained result is depicted in Fig. 5a.

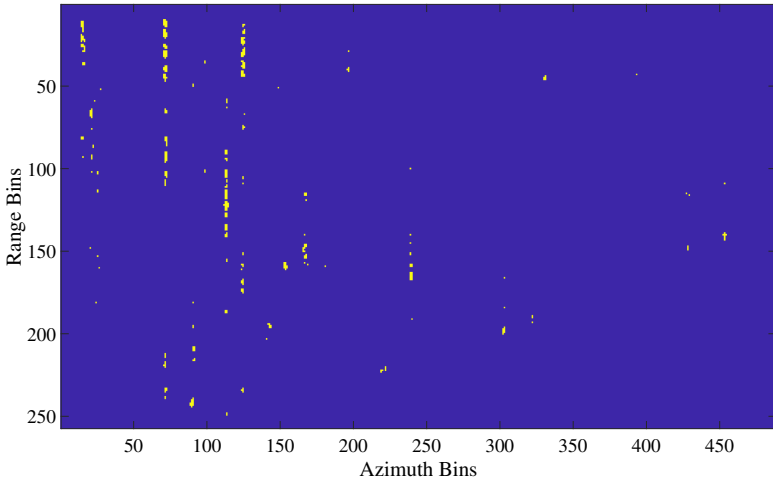
The threshold calculated by the 2D-CFAR changes according to the elements around the Cell Under Test (CUT) so the threshold is adaptive along with the map and in this way the clutter is reduced. Only the CUTs where the intensity value is over the threshold are revealed. The values of the final map are zero or one according to whether the threshold has been exceeded or not. The application of the 2D-CFAR threshold provides the positions of the possible targets; when they occupy more CUTs by applying the DBSCAN technique [5] the points are grouped and a single target is revealed. The best performance for this algorithm is provided from a DBSCAN with a square-euclidean distance of ten and the minimum number of points that compose a target equal to five. An example result can be found in Fig. 5b.

With the aim to study the movements of the people inside the garden it is necessary to remove the background, due to the signal reflected by the static objects. These are elements inside the DBSCAN result maps and to remove them the Mixture of Gaussian (MoG) algorithm is applied [2]. The result of MoG applied to the maps after the DBSCAN is depicted inside Fig. 6.

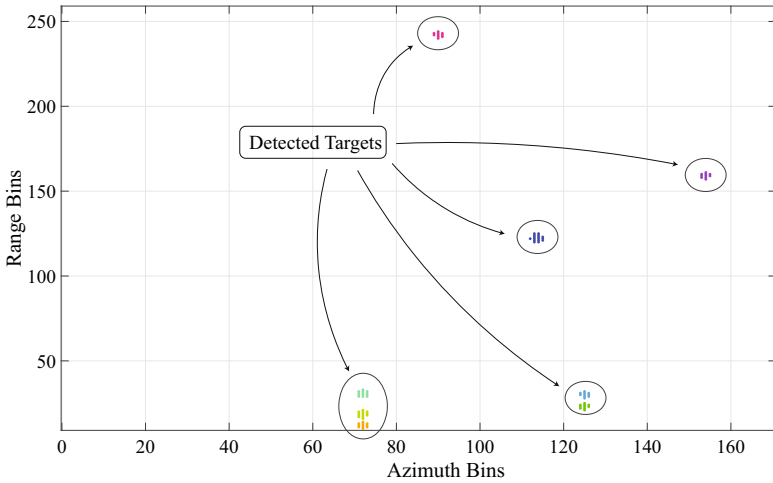
After retrieving all the maps using the background Subtraction algorithm the Tracker Video Analysis and Modeling tool is used for tracking the movement of the people inside the observed area [4].

4 Experimental Tests and Results

In order to test and compare the different acquisition systems, four different tests were performed:



(a)



(b)

Fig. 5. Target detection procedure: a) example of the application of the 2D-CFAR on the Range-Azimuth map; b) resulting map after the DBSCAN application.

- two thirty-minute acquisitions with many people involved;
- a ten-minute acquisition with only two people involved;
- a five-minute acquisition with only two people involved;

The position of the radars are chosen properly to obtain as much information from the individual people that were doing different activities like walking, sitting on chair, and others. In Fig. 7 the path of one subject during all the time of the

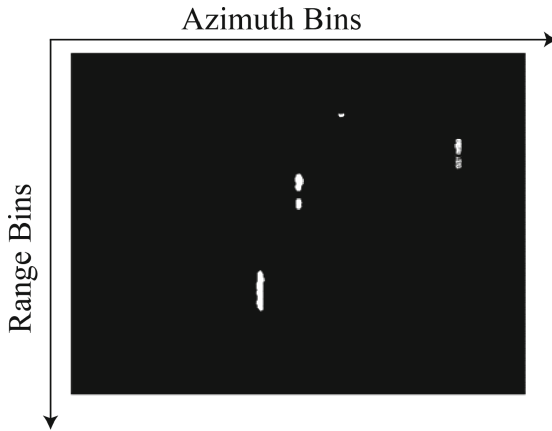


Fig. 6. Application of the MoG background removal to the DBSCAN maps.

measurement is shown, as received by each radar. Since the detection range of the radar is smaller than the size of the garden, the final image of the trajectory is obtained by merging the data from both radars. The radar acquisitions started at the same time and have the same duration. In this time the subjects moved from the area covered by one radar to the other one. During the measurements different targets are observed and the main problem is related to the impossibility with the proposed method to identify the targets when moving from one area to another. An exact evaluation requires the presence of only one subject moving at a time; when two or more subjects are walking very close each other a big margin of error may arise, that can be reduced with a proper radar calibration. However, the performance of the radar is a compromise between all the configuration parameters and depends on the hardware limits of the system used, and therefore it is not possible to obtain at the same time a high radar visibility range and a high discrimination capacity of nearby objects. At the same time, the garden considered is a very dense environment with various obstacles that interfere with the acquisitions, thus making it difficult to extract information relating to the subjects from the received signal, which in this particular case move slowly. The evaluation of how much time a person has stayed in a specific location can be based on the association of the coordinates for each frame with the frame time.

As described in Sect. 2.2, the GPS data provided by the smartwatches can be processed through the commercial software provided by the vendor and through the custom software developed by the authors, both methods which provide very similar results. In Fig. 8 the paths obtained with two smartwatches of the same model worn by two different people walking very close to each other are represented. It is evident from the figure that the two paths are different in more points. In fact, even if the two smartwatches are very close to each other, the different positions on the arms of the two people, and the attenuation of the Radio Frequency due to trees and buildings on the perimeter, lead to different reception conditions of GPS satellite signals, thus providing different results.

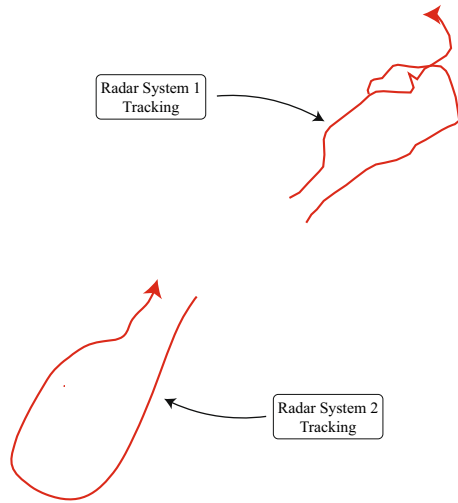


Fig. 7. Example result for the radar system tracking, for only one person in the garden.

A comparison of all the methods described above is depicted in Fig. 9. From the figure is possible to see a good matching of the methods, all providing good performances in tracking the position of the subjects. As introduced above, the main differences are due to the characteristics of the measurements area where



Fig. 8. Result obtained with the GPS for two people walking inside the garden. The blue line is related to the cloud processing and the red line to the custom developed processing. (Color figure online)

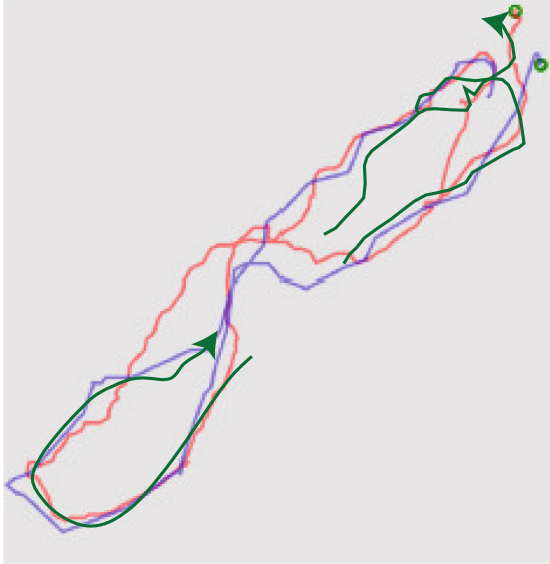


Fig. 9. Comparison between all the methods applied, the green line are the radar systems results, the blue line GPS data processed on cloud and the red with the custom-developed software. (Color figure online)

walls, fences, and trees reduce the radar performances and the GPS performances. However, the tested technological system appears to be appropriate for the purposes envisaged by the project's aims. In fact, even if in the presence of differences in the paths obtained, the sensory areas identify in the garden some macro-sectors within which the presence or absence of patients, and the duration of their presence, can be determined with excellent precision.

5 Conclusions

In this work, a mmWave radar system and two smartwatches equipped with GPS are used to monitoring people inside a garden area. Each system can detect the position and provides information about which area of the garden is preferred by the people who frequent it. Each method provides good performance but the radar system suffers issues coming from the object inside the area such as trees and fences. For this reason, a background removal technique is applied to facilitate the tracking process. The GPS technique is more reliable and the processing of the data is more simple but each person must wear the device and synchronization of all the systems can be difficult. In conclusion, the radar system can detect the targets, the processing technique used to study the environment can be implemented directly on the device and the privacy of each subject can also be preserved. With the smartwatch, the analysis is easier as the information is provided by the GPS but this solution requires each person to wear the device,

and that the data is downloaded daily from the smartwatch, which must be frequently recharged anyway.

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